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Agrawal

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(54) METHOD FOR DETERMINING CIRCUMFERENTIAL SENSOR POSITIONING

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(51) **Int. Cl.**

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G01M 15/14	(2006.01)
F02C 7/32	(2006.01)
G01K 1/14	(2006.01)
G01K 13/02	(2006.01)

(52) **U.S. Cl.**

CPC ***G01K 3/06*** (2013.01); ***F02C 7/32*** (2013.01); ***G01K 1/143*** (2013.01); ***G01M 15/14*** (2013.01); *F05D 2220/32* (2013.01); *F05D 2230/60* (2013.01); *F05D 2260/83* (2013.01); *G01K 2013/024* (2013.01); *G01K 2205/00* (2013.01); *Y10T 29/49826* (2015.01)

(58) **Field of Classification Search**

CPC F01D 17/02; F01D 21/003; F01D 17/085; F02C 7/32; F02C 9/28; F05D 2260/83; F05D 2270/334; F05D 2270/80; F05D 2230/60; G01K 1/146; G01K 3/02; G01K 3/06; G01M 15/14

See application file for complete search history.

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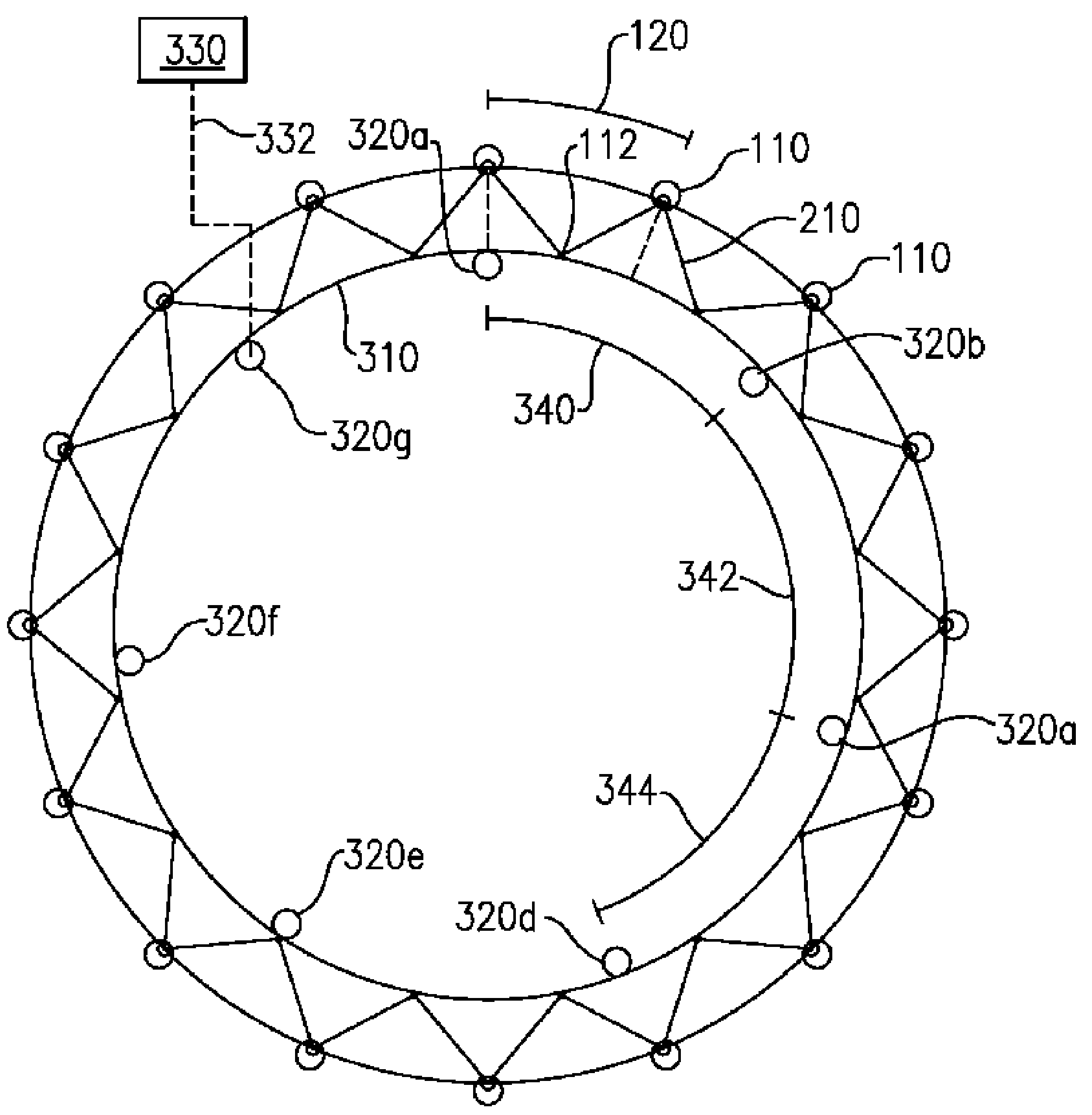
(57) ABSTRACT

A method for positioning sensors about a sensor ring includes the steps of assigning each sensor in a plurality of sensors a sensor number selected from a set of sensor numbers, where the set of sensor numbers is a whole number in the range of 0 to N, and where N is the total number of sensors in said plurality of sensors minus one, disposing a first sensor at a circumferential angular position zero on the sensor ring, and disposing each sensor in the plurality of sensors at a circumferential angular position about the sensor ring, wherein the circumferential angular position is defined by an offset from a circumferential angular position zero and the offset is equal to a base arc length between sensors multiplied by the sensor number of the sensor plus a base offset arc length multiplied by the sensor number of the sensor.

7 Claims, 4 Drawing Sheets



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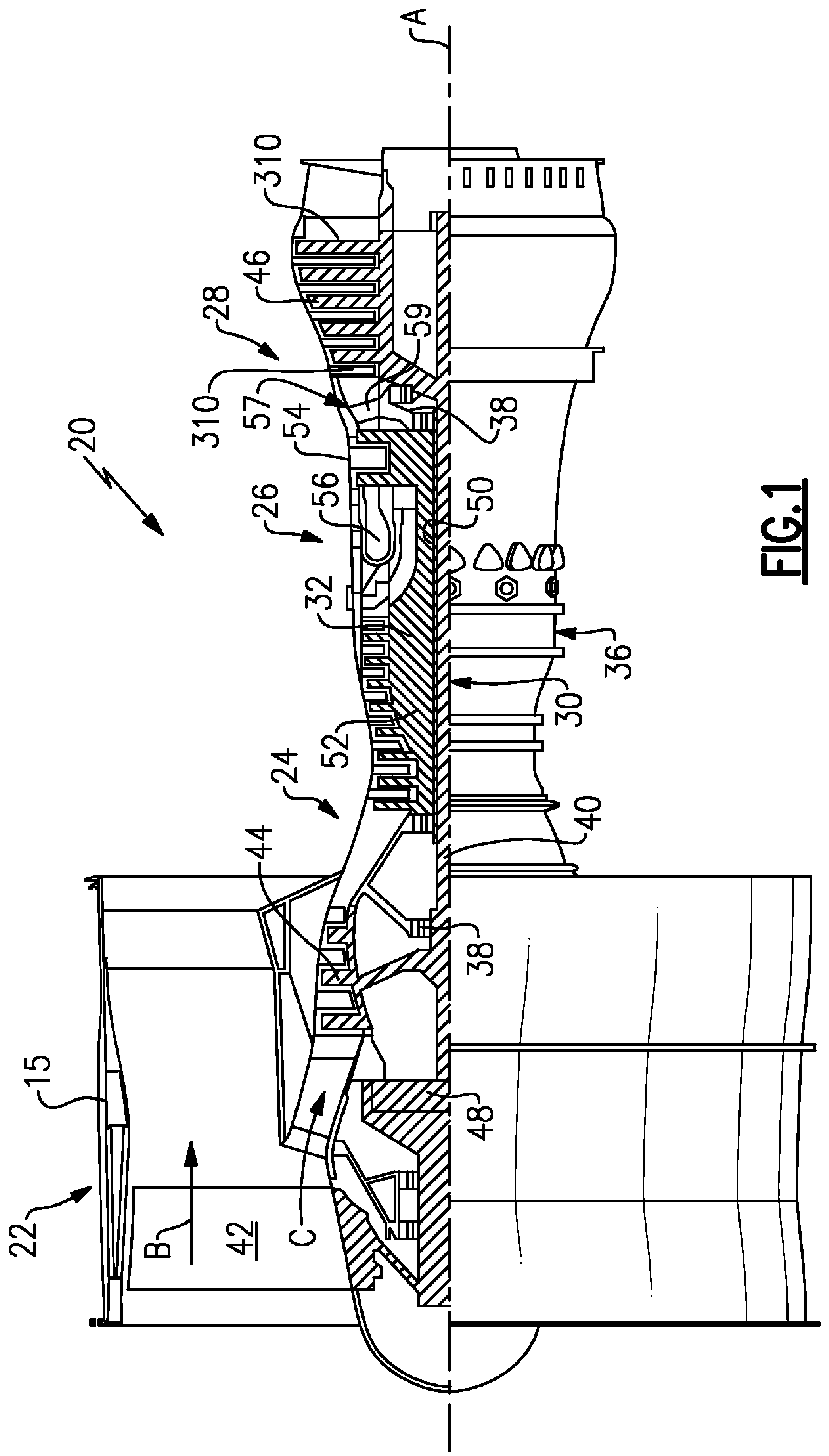
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B
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C
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48
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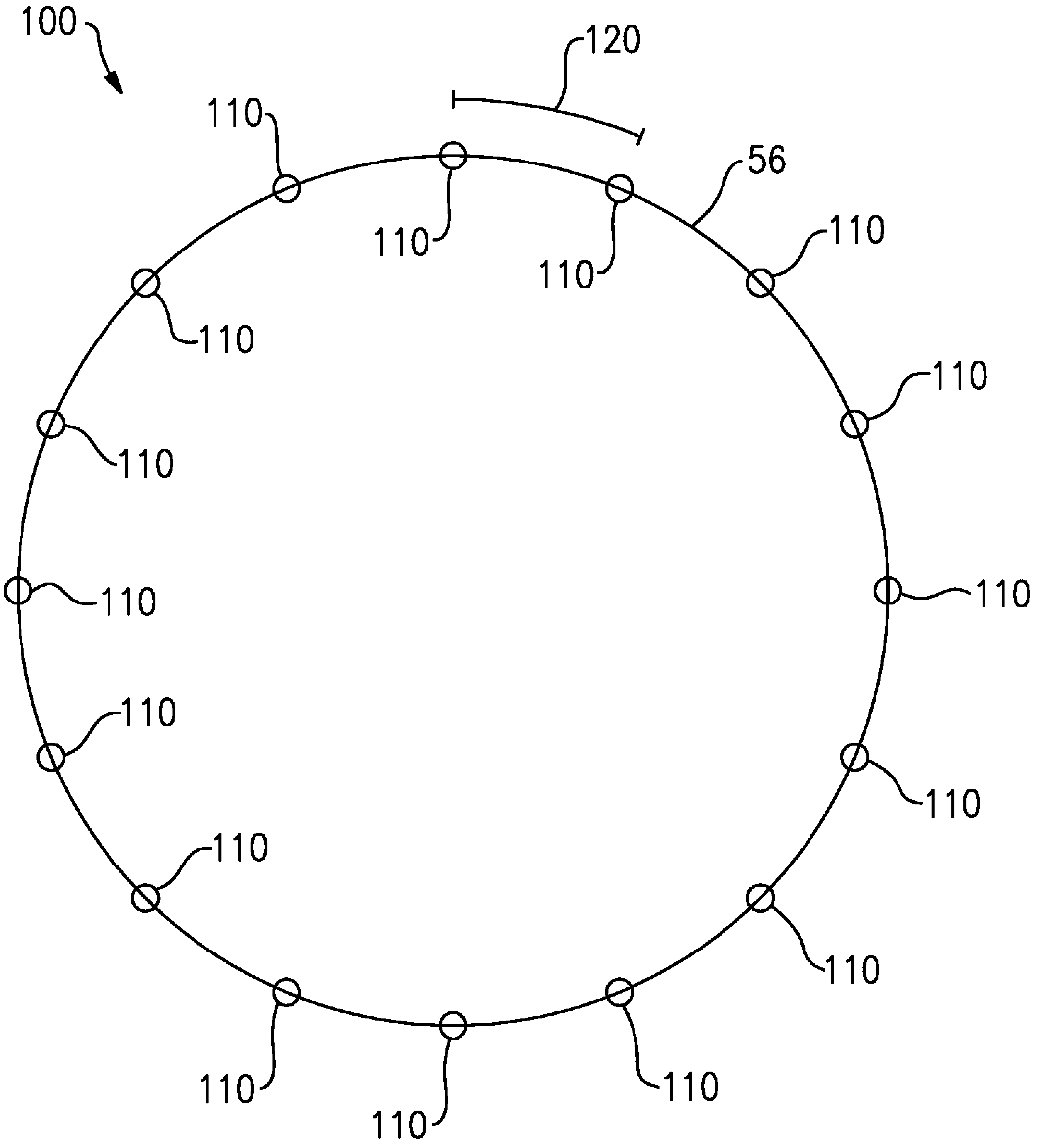
310
A

FIG.1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120
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FIG.2

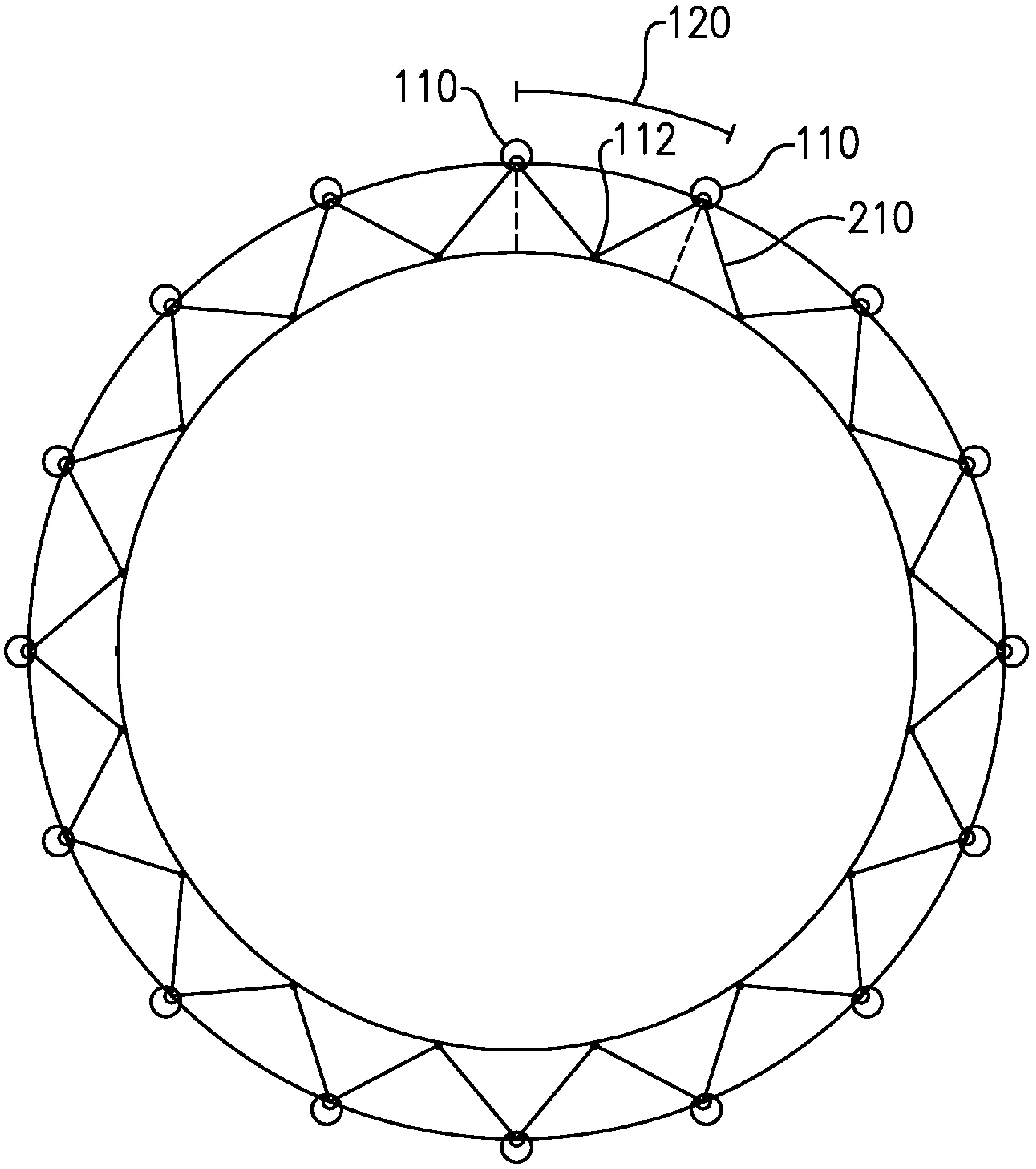

FIG.3

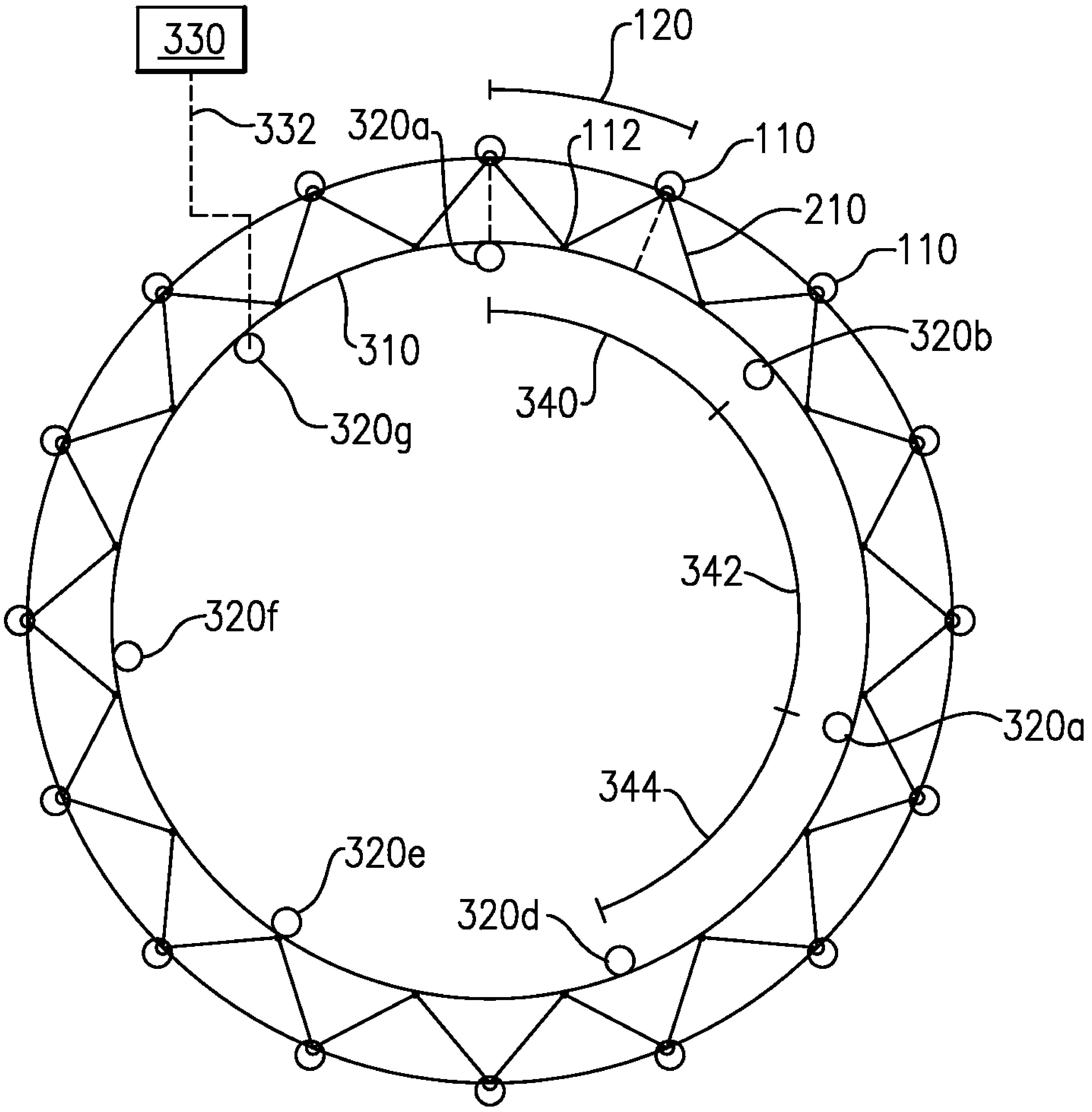
330
332
320a
112
120
110
210
110
310
320b
340
320g
342
320f
320a
344
320e
320d

FIG.4

METHOD FOR DETERMINING CIRCUMFERENTIAL SENSOR POSITIONING

This application claims priority to U.S. Provisional Application No. 61/874,378 filed Sep. 6, 2013.

TECHNICAL FIELD

The present disclosure relates generally to sensor rings, and more particularly to a method for determining radial positioning of sensors on a sensor ring.

BACKGROUND OF THE INVENTION

Gas turbine engines, such as those used in commercial aircraft, utilize a compressor, combustor and turbine section arranged sequentially in an engine core to generate thrust and propel the aircraft forward. During operation of the gas turbine engine multiple variables are measured and detected via sensors disposed circumferentially about the turbine engine. This sensor arrangement is referred to as a sensor ring. The sensed variables can include turbine exhaust temperatures, exhaust pressures, or any other necessary variable. While the instant disclosure discusses turbine exhaust variables specifically, it is understood that the same method can be applied to any similar system including augmenter inlets and exhausts.

One metric measured during operation of the gas turbine engine is the turbine exhaust temperature and/or the power turbine inlet temperature. These temperature measurements are utilized to ensure that the gas turbine engine operates within the allowable safe average temperature limits of the engine. When the turbine engine exceeds the allowable safe average temperature for longer than a pre-defined period of time, the turbine engine must be removed from the wing and undergo maintenance or be replaced. As described above, these temperature measurements are typically made using multiple temperature sensors that are disposed evenly circumferentially about a sensor ring at the turbine exhaust or at the power turbine inlet. This measurement scheme provides an "average" temperature of the gasses passing through the turbine exhaust or the power turbine inlet.

In practice, turbine engine designs utilize multiple fuel nozzles disposed circumferentially about a combustor to inject fuel into the combustor. As a result of the fuel nozzle placement, the temperature profile at the turbine exhaust or at the power turbine inlet is not even circumferentially. As the sensors are disposed evenly circumferentially, and the temperature profile is not even circumferentially, the determined average is skewed, and can be off by as much as 150-200 degrees Fahrenheit.

SUMMARY OF THE INVENTION

A gas turbine engine according to an exemplary embodiment of this disclosure, among other possible things includes a compressor section, a combustor fluidly connected to the compressor section via a core flow path, the combustor including a plurality of fuel nozzles and the plurality of fuel nozzles are disposed evenly circumferentially about the combustor, a turbine section fluidly connected to the combustor section via the core flow path, a plurality of sensors disposed circumferentially about the core flow path, each sensor in the plurality of sensors has a sensor number selected from a set of sensor numbers, where the set of sensor numbers is a whole number in the range of 0 to N, where N is the total number of sensors in the plurality of sensors minus one, and each sensor of the plurality of sensors is offset circumferentially from a circumferential angular position zero the offset is equal to a base arc length between sensors multiplied by the sensor number of the sensor plus a base offset arc length multiplied by the sensor number of the sensor.

In a further embodiment of the foregoing gas turbine engine, the base arc length between sensors is 360 divided by the quantity of sensors in the plurality of sensors.

In a further embodiment of the foregoing gas turbine engine, the base offset arc length is a nozzle arc length divided by the quantity of sensors in the plurality of sensors.

In a further embodiment of the foregoing gas turbine engine, the nozzle arc length is 360 divided by the number of fuel nozzles.

In a further embodiment of the foregoing gas turbine engine, each sensor in the plurality of sensors has a unique whole number in the range of 0 to N.

In a further embodiment of the foregoing gas turbine engine, the number of fuel nozzles is 16 and the nozzle arc length is approximately 22.5 degrees.

In a further embodiment of the foregoing gas turbine engine, the number of sensors is 7 and the base arc length is approximately 51.4 degrees.

In a further embodiment of the foregoing gas turbine engine, the base offset arc length is approximately 3.21 degrees.

A sensor ring for determining an average sensed value about the ring according to an exemplary embodiment of this disclosure, among other possible things includes a plurality of sensors disposed circumferentially about the sensor ring, each sensor in the plurality of sensors has a sensor number selected from a set of sensor numbers, where the set of sensor numbers is a whole number in the range of 0 to N, where N is the total number of sensors in the plurality of sensors minus one, and each sensor of the plurality of sensors being offset circumferentially from a circumferential angular position zero the offset is equal to a base arc length between sensors multiplied by the sensor number of the sensor plus a base offset arc length multiplied by the sensor number of the sensor.

In a further embodiment of the foregoing sensor ring, the base arc length between sensors is 360 divided by the quantity of sensors in the plurality of sensors.

In a further embodiment of the foregoing sensor ring, the base offset arc length is a peak to peak arc length divided by the quantity of sensors in the plurality of sensors.

In a further embodiment of the foregoing sensor ring, the peak to peak arc length is 360 divided by the number of peaks of a sensed value disposed circumferentially about the ring.

In a further embodiment of the foregoing sensor ring, each sensor in the plurality of sensors has a unique whole number in the range of 0 to N.

In a further embodiment of the foregoing sensor ring, the base offset arc length is a peak to peak arc length divided by the whole number factor of the quantity of sensors in the plurality of sensors.

A method for positioning sensors about a sensor ring according to an exemplary embodiment of this disclosure, among other possible things includes assigning each sensor in a plurality of sensors a sensor number selected from a set of sensor numbers, where the set of sensor numbers is a whole number in the range of 0 to N, where N is the total number of sensors in the plurality of sensors minus one disposing a first sensor at a circumferential angular position zero on the sensor ring, disposing each sensor in the plurality of sensors at a circumferential angular position about the sensor ring, the circumferential angular position is defined by an offset from a circumferential angular position zero and the offset is equal to a base arc length between sensors multiplied by the sensor number of the sensor plus a base offset arc length multiplied by the sensor number of the sensor.

A further embodiment of the foregoing method includes the step of determining the base arc length between sensors by dividing 360 by the number of sensors.

A further embodiment of the foregoing method includes the step of determining the base offset arc length for each sensor by dividing a peak to peak arc length by the quantity of sensors in the plurality of sensors.

A further embodiment of the foregoing method includes the step of determining the peak to peak arc length by dividing 360 by a total number of expected peaks disposed circumferentially about the ring of the value to be sensed.

These and other features of the present invention can be best understood from the following specification and drawings, the following of which is a brief description.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** schematically illustrates a gas turbine engine.

FIG. **2** schematically illustrates a fuel nozzle arrangement for the gas turbine engine of FIG. **1**.

FIG. **3** schematically illustrates a temperature profile of power turbine inlet gasses originating from a combustor.

FIG. **4** schematically illustrates a sensor ring for a power turbine inlet of the gas turbine engine of FIG. **1**.

DETAILED DESCRIPTION OF AN EMBODIMENT

FIG. **1** schematically illustrates a gas turbine engine **20**. The gas turbine engine **20** is disclosed herein as a two-spool turbofan that generally incorporates a fan section **22**, a compressor section **24**, a combustor section **26** and a turbine section **28**. Alternative engines might include an augmentor section (not shown) among other systems or features. The fan section **22** drives air along a bypass flow path B in a bypass duct defined within a nacelle **15**, while the compressor section **24** drives air along a core flow path C for compression and communication into the combustor section **26** then expansion through the turbine section **28**. Although depicted as a two-spool turbofan gas turbine engine in the disclosed non-limiting embodiment, it should be understood that the concepts described herein are not limited to use with two-spool turbofans as the teachings may be applied to other types of turbine engines including three-spool architectures.

The exemplary engine **20** generally includes a low speed spool **30** and a high speed spool **32** mounted for rotation about an engine central longitudinal axis A relative to an engine static structure **36** via several bearing systems **38**. It should be understood that various bearing systems **38** at various locations may alternatively or additionally be provided, and the location of bearing systems **38** may be varied as appropriate to the application.

The low speed spool **30** generally includes an inner shaft **40** that interconnects a fan **42**, a low pressure compressor **44** and a low pressure turbine **46**. The inner shaft **40** is directly connected to the fan **42** or connected through a speed change mechanism, which in exemplary gas turbine engine **20** is illustrated as a geared architecture **48** to drive the fan **42** at a lower speed than the low speed spool **30**. The high speed spool **32** includes an outer shaft **50** that interconnects a high pressure compressor **52** and high pressure turbine **54**. A combustor **56** is arranged in exemplary gas turbine **20** between the high pressure compressor **52** and the high pressure turbine **54**. A mid-turbine frame **57** of the engine static structure **36** is arranged generally between the high pressure turbine **54** and the low pressure turbine **46**. The mid-turbine frame **57** further supports bearing systems **38** in the turbine section **28**. The inner shaft **40** and the outer shaft **50** are concentric and rotate via bearing systems **38** about the engine central longitudinal axis A which is collinear with their longitudinal axes.

The core airflow is compressed by the low pressure compressor **44** then the high pressure compressor **52**, mixed and burned with fuel in the combustor **56**, then expanded over the high pressure turbine **54** and low pressure turbine **46**. The mid-turbine frame **57** includes airfoils **59** which are in the core airflow path C. The turbines **46**, **54** rotationally drive the respective low speed spool **30** and high speed spool **32** in response to the expansion. It will be appreciated that each of the positions of the fan section **22**, compressor section **24**, combustor section **26**, turbine section **28**, and fan drive gear system **50** may be varied. For example, gear system **50** may be located aft of combustor section **26** or even aft of turbine section **28**, and fan section **22** may be positioned forward or aft of the location of gear system **48**.

The engine **20** in one example is a high-bypass geared aircraft engine. In a further example, the engine **20** bypass ratio is greater than about six (6), with an example embodiment being greater than about ten (10), the geared architecture **48** is an epicyclic gear train, such as a planetary gear system or other gear system, with a gear reduction ratio of greater than about 2.3 and the low pressure turbine **46** has a pressure ratio that is greater than about five. In one disclosed embodiment, the engine **20** bypass ratio is greater than about ten (10:1), the fan diameter is significantly larger than that of the low pressure compressor **44**, and the low pressure turbine **46** has a pressure ratio that is greater than about five 5:1. Low pressure turbine **46** pressure ratio is pressure measured prior to inlet of low pressure turbine **46** as related to the pressure at the outlet of the low pressure turbine **46** prior to an exhaust nozzle. The geared architecture **48** may be an epicycle gear train, such as a planetary gear system or other gear system, with a gear reduction ratio of greater than about 2.3:1. It should be understood, however, that the above parameters are only exemplary of one embodiment of a geared architecture engine and that the present invention is applicable to other gas turbine engines including direct drive turbofans, turbojets, turboshafts and turboprop engines.

A significant amount of thrust is provided by the bypass flow B due to the high bypass ratio. The fan section **22** of the engine **20** is designed for a particular flight condition—typically cruise at about 0.8 Mach and about 35,000 feet. The flight condition of 0.8 Mach and 35,000 ft, with the engine at its best fuel consumption—also known as "bucket cruise Thrust Specific Fuel Consumption ('TSFC')"—is the industry standard parameter of lbm of fuel being burned divided by lbf of thrust the engine produces at that minimum point. "Low fan pressure ratio" is the pressure ratio across the fan blade alone, without a Fan Exit Guide Vane ("FEGV") system. The low fan pressure ratio as disclosed herein according to one non-limiting embodiment is less than about 1.45. "Low corrected fan tip speed" is the actual fan tip speed in ft/sec divided by an industry standard temperature correction of $[(\text{Tram}^\circ \text{ R})/(518.7^\circ \text{ R})]^{0.5}$. The

"Low corrected fan tip speed" as disclosed herein according to one non-limiting embodiment is less than about 1150 ft/second.

FIG. **2** schematically illustrates a fuel nozzle arrangement **100** about the combustor **56** of the gas turbine engine **20** of FIG. **1**. The illustrated combustor **56** includes sixteen fuel nozzles **110** arranged circumferentially about the combustor **56**. The fuel nozzles **110** inject fuel into the combustor **56** according to known turbine engine practices. The fuel nozzles **110** are spaced evenly circumferentially about the combustor **56**. A fuel nozzle arc length **120** from each fuel nozzle **110** to each adjacent fuel nozzle **110** is determined by dividing 360 degrees by sixteen (the total number of fuel nozzles **110**.) In the example utilizing sixteen fuel nozzles, the fuel nozzle arc length **120** is approximately 22.5 degrees. Thus, each fuel nozzle **110** is spaced 22.5 degrees from each adjacent fuel nozzle **110** about the circumference of the combustor **56**.

In similar sensor arrangements, not directed toward sensing the temperature of combustion products, the "fuel nozzle" locations are referred to as peak locations, and are located at each circumferential location where the sensed characteristic is at a peak value. Similarly, the arc length from each peak to each adjacent peak (the fuel nozzle arc length **120** in the illustrated example) is referred to as the peak to peak arc length, and is 360 degrees divided by the total number of peaks.

Each of the fuel nozzles **110** injects fuel into the combustor **56** in a discrete location, and the fuel spreads out from that location before being combusted. As a result of this arrangement, the fuel is most heavily concentrated at each of the fuel nozzle **110** locations, and has the lowest concentration at the midpoints between each of the fuel nozzles **110**. The lower fuel concentration results in less combustion and a lower gas temperature at the mid-point, with a temperature gradient that increases as you approach the fuel nozzle locations. The resulting temperature profile is that of a waveform, and is sinusoidal in nature. A similar characteristic profile can be seen in non-fuel nozzle configurations having peaks and valleys.

With continued reference to FIG. **2**, and with like numerals indicating like elements, FIG. **3** illustrates an example temperature profile **210** of the exhaust gasses from the fuel nozzle arrangement of FIG. **2**. The temperature profile illustrated in FIG. **3** is a triangle waveform with the temperature at its peak at each of the fuel nozzles **110**, and at its minimum at a point **112** equidistant from, and between, each of the fuel nozzles **110**. While the temperature profile in the illustrated example is a triangle wave, it is understood that the profile can be any profile having a repeating waveform, including a sinusoidal waveform and the illustrated triangle waveform and the below described sensor arrangement will still be applicable.

In order to ensure that the gas turbine engine **20** operates within the allowable safe temperature limits of the engine **20**, a sensor ring **310** is placed at either a turbine section exhaust or a power turbine inlet portion and detects the temperature of the gas passing through the ring **310**. With continued reference to FIGS. **2** and **3**, and with like numerals indicating like elements, FIG. **4** illustrates a sensor ring **310** including seven sensors **320***a-g* (alternately referred to as probes) disposed circumferentially about the sensor ring **310**. The sensors **320***a-g* each measure the temperature at the sensor **320***a-g* location and report the sensed values to a controller **330**. The controller **330** is connected to each of the sensors **320***a-g* via a physical connection **332**. In alternate examples, a wireless connection between the sensors **320***a-g* and the controller **330** can be utilized.

The controller **330** determines the average sensed temperature from all the sensors **320***a-g*, and defines that temperature as the average temperature of the combustor gasses. When the sensors **320***a-g* are distributed evenly circumferentially about sensor ring **310**, that is to say an arc length **340** between each of the sensors **320***a-g* and each adjacent sensor **320***a-g* is equal as in the prior art, the sensed positions on the temperature profile waveform **210** do not net a true average value of the temperature. In order to account for this factor, the arc lengths **340**, **342**, **344**, etc between each sensor **320***a-g* and the adjacent sensors **320***a-g* varies from sensor **320***a-g* to sensor **320***a-g* according to a mathematically derived angular offset.

The variance between the arc lengths **340**, **342**, **344** is a base sensor arc length of 360 degrees divided by the number of sensors **320***a-g* (360 degrees divided by 7=51.4 degrees for the illustrated example) plus an arc length offset value of the fuel nozzle arc length **120** divided by the number of sensors **320***a-g* (22.5 degrees divided by 7=3.21 degrees for the illustrated example.) Thus, each sensor **320***a-g* is offset from the previous adjacent sensor by 54.61 degrees.

Described below is a method for determining the particular circumferential positions of each sensor **320***a-g* relative to a set angular position zero rather than positioning the sensors uniformly around the circumference.

An initial sensor **320***a* is placed at a circumferential angular position that is arbitrarily assigned as zero degrees (position zero.) Each sensor **320***a-g* is also assigned a sensor number from 0 to n, where n is the total number of sensors **320***a-g* minus one. Each sequential sensor **320***b-g* is offset circumferentially from the angular position zero by an arc length defined as a base sensor arc length plus an arc length offset value multiplied by the corresponding assigned sensor number. The base sensor arc length is 360 degrees divided by the total number of sensors **320***a-g* on the sensor ring **310** and the arc length offset value is defined as the fuel nozzle arc length **120** (alternately referred to as the peak to peak arc length) divided by the number of sensors **320***a-g*.

Thus, in the sixteen fuel nozzle **110**, seven probe **320***a-g* example illustrated in the figures, the first sensor **320***a* is assigned sensor number zero and is located at the circumferential angular position zero (the base sensor arc length times zero plus the arc length offset times zero is zero degrees.) The second sensor **320***b* is assigned sensor number one and is offset from the angular position zero by approximately 54.61 degrees (the base arc length of 51.4 degrees times one plus the arc length offset of 3.21 degrees times one). The third sensor **320***c* is assigned sensor number two, and is offset from angular position zero by approximately 109.22 degrees (the base arc length of 51.4 degrees times two plus the arc length offset of 3.21 degrees times two.) The angular position of each sensor **320***a-g* is determined similarly.

By positioning the sensors **320***a-g* using the above described circumferential positioning schemes, the sensors **320***a-g* are placed at distributed relative positions on the waveform **210**. In contrast, locating the sensors **320***a-g* evenly circumferentially can result in the sensors **320***a-g* sensing the same relative positions on the waveform **210**. Thus, the average sensed value of the sensors **320***a-g* in the above described circumferential distribution is a truer average value than can be achieved by distributing the sensors **320***a-g* evenly about the sensor ring **310**.

One of skill in the art, having the benefit of this disclosure will also recognize that the base offset arc length can be the peak to peak arc length divided by a whole number factor of the total number of sensors **320***a*-*g*, rather than the total number of sensors **320***a*-*g* and achieve similar results. Using a whole number factor of the total number of sensors decreases the number of relative positions being sensed on the waveform and causes each relative position to be sensed at least twice. The number of times each relative position is sensed is dependent on the particular whole number factor utilized.

While the above descriptions and Figures are directed toward a temperature sensor for detecting an average temperature in a gas turbine engine, it is understood that the method for determining sensor positioning, and the corresponding sensor ring can be applied to any circumferential sensor arrangement where the sensed characteristics has a waveform shaped profile, and is not limited to combustor temperature sensor rings. Similarly, while the above described arrangement utilizes sixteen peak sensed characteristic locations, and seven sensor locations, one of skill in the art, having the benefit of this disclosure, can apply the disclosure to an arrangement having any number of peak locations and any number of sensors, while still remaining within the disclosed invention.

It is further understood that any of the above described concepts can be used alone or in combination with any or all of the other above described concepts. Although an embodiment of this invention has been disclosed, a worker of ordinary skill in this art would recognize that certain modifications would come within the scope of this invention. For that reason, the following claims should be studied to determine the true scope and content of this invention.

The invention claimed is:

1. A gas turbine engine comprising:

a compressor section;

a combustor fluidly connected to the compressor section via a core flow path, the combustor including a plurality of fuel nozzles having a total number of fuel nozzles, the plurality of fuel nozzles are disposed evenly circumferentially about the combustor;

a turbine section fluidly connected to the combustor via the core flow path;

a plurality of sensors having a total number of sensors, the plurality of sensors disposed circumferentially about the core flow path, the total number of sensors is not equal to the total number of fuel nozzles;

each sensor in said plurality of sensors has a respective sensor number selected from a set of sensor numbers, where each respective sensor number in the set of sensor numbers is a unique whole number in a range of 0 to N, where N is equal to the total number of sensors minus one; and

each sensor of said plurality of sensors is positioned at a respective circumferential offset relative to a circumferential angular position zero, wherein the respective circumferential offset is equal to a base arc length multiplied by the respective sensor number of the sensor plus a base offset arc length multiplied by the respective sensor number of the sensor, the base arc length is 360 degrees divided by the total number of sensors, the base offset arc length is a nozzle arc length divided by the total number of sensors, and the nozzle arc length is 360 degrees divided by the total number of fuel nozzles, wherein the circumferential angular position zero is a circumferential angular position of one of the plurality of fuel nozzles.

2. The gas turbine engine of claim **1**, wherein the total number of fuel nozzles is 16.

3. The gas turbine engine of claim **1**, wherein the total number of sensors is 7.

4. The gas turbine engine of claim **1**, wherein the base offset arc length is approximately 3.21 degrees.

5. The gas turbine engine of claim **1**, wherein the nozzle arc length is an arc length from each fuel nozzle to each adjacent fuel nozzle in the plurality of fuel nozzles.

6. A sensor ring for determining an average sensed value about the sensor ring comprising:

a plurality of sensors disposed circumferentially about said sensor ring for measuring a parameter, the plurality of sensors having a total number of sensors;

wherein the sensor ring has a plurality of expected peaks disposed circumferentially about said sensor ring, wherein each of the plurality of expected peaks corresponds to an expected local peak value of the parameter, the plurality of expected peaks having a total number of expected peaks;

wherein each sensor in said plurality of sensors has a respective sensor number selected from a set of sensor numbers, where each respective sensor number in the set of sensor numbers is a unique whole number in the range of 0 to N, where N is equal to the total number of sensors minus one; and

each sensor of said plurality of sensors is positioned at a respective circumferential offset relative to a circumferential angular position zero, wherein the respective circumferential offset is equal to a base arc length multiplied by the respective sensor number of the sensor plus a base offset arc length multiplied by the respective sensor number of the sensor, the base arc length is equal to 360 degrees divided by the total number of sensors, the base offset arc length is equal to a peak to peak arc length divided by the total number of sensors, and the peak to peak arc length is equal to 360 degrees divided by the total number of expected peaks; and

the total number of sensors is not equal to the total number of expected peaks, wherein the circumferential angular position zero is a circumferential angular position of one of the plurality of expected peaks.

7. A method for positioning a plurality of sensors about a sensor ring for measuring a parameter, the sensor ring having a plurality of expected peaks disposed circumferentially about said sensor ring, wherein each of the plurality of expected peaks corresponds to an expected local peak value of the parameter, the plurality of sensors having a total number of sensors and the plurality of expected peaks having a total number of expected peaks, the method comprising the steps of:

assigning each sensor in the plurality of sensors a respective sensor number selected from a set of sensor numbers, where each respective sensor number in the set of sensor numbers is a unique whole number in the range of 0 to N, where N is the total number of sensors minus one;

disposing each sensor in said plurality of sensors at a respective circumferential angular position about said sensor ring, wherein the respective circumferential angular position is defined by a respective circumferential offset relative to a circumferential angular position zero, the respective circumferential offset is equal to a base arc length multiplied by the respective sensor number of the sensor plus a base offset arc length multiplied by the respective sensor number of the sensor, the base arc length is equal to 360 degrees divided by the total number of sensors, the base offset arc length is equal to a peak to peak arc length divided by the total number of sensors, and the peak to peak arc length is equal to 360 degrees divided by the total number of expected peaks; and

the total number of sensors is not equal to the total number of expected peaks, wherein the circumferential angular position zero is a circumferential angular position of one of the plurality of expected peaks.

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